

## 560 YEARS OF VEGETATION CHANGE IN THE REGION OF SANTA BARBARA, CALIFORNIA

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### ABSTRACT

Pollen evidence from two sites in the Santa Barbara region show evidence of vegetation changes following European settlement in California. In the Santa Barbara coastal region, oak woodland populations (dominated by *Quercus agrifolia*) remained stable during the pre-European period; however, in the last century woodland densities have increased. At higher elevations along the oak woodland/pine forest ecotone, pines are becoming dominant. Reduction in fire frequency has probably been the main factor contributing to density increases. The pollen record does not show any evidence of an expansion of chaparral over the last 200 years; however, there is weak evidence for an increase in coastal-sage scrub since the early 1800's. The transformation of the California grassland appears to have begun particularly early with the invasion of *Erodium cicutarium* in the region even before the first Spanish settlement in California.

With the settlement of Spanish Missionaries, beginning in 1769, the California landscape has been radically altered by human-caused environmental change. The exact nature of these changes is not always readily apparent, since descriptions of the pre-European vegetation are sketchy at best, and by the time reliable botanical records were gathered, much of the landscape had already been altered. The vegetation we see today represents the dynamic result of two centuries of response to various changes, including changes in fire regime, introduction of livestock, invasion of alien species, and land clearing for agriculture and urban development. Understanding how vegetation has changed in response to these impacts can provide valuable information for present-day conservation efforts.

Of particular concern recently has been the affect of human-caused environmental changes in oak woodlands (Muick and Bartolome 1987; Bolsinger 1988). To date, no high resolution paleoecologic studies have been conducted that document environmental change in regions dominated by California oak woodland. A variety of methods have been used to reconstruct past change in California oak woodlands, including age structure studies (White 1966; Vankat and Major 1978; Anderson and Pasquinelli 1984; McClaran 1986; McClaran and Bartolome 1989; Mensing 1992), historical records (Mayfield 1981; Rossi 1980), analysis of aerial photographs (Brown and Davis 1991), and resurveying of permanent plots (Holzman 1993). These studies have contributed significant information on oak woodland history; however, they are generally restricted to the last 200 years and reveal little about the pre-European period.

Pollen analysis from an estuarine sediment core on Santa Rosa Island in the Santa Barbara Channel has documented the invasion of exotic taxa and changes in native vegetation following the settlement of the island in the late 1800's (Cole and Liu

1994). Radiocarbon dates from the top three meters of core however are influenced by old carbon effects which suggest that the bulk sediment dates may be 1200 years too old. The chronology for the historic period therefore was extrapolated from exotic pollen types. Oak pollen was only a minor component of the pollen sum and is not discussed by the authors.

In this paper I use pollen evidence from two sites in the Santa Barbara region to reconstruct vegetation history for the last 560 years. The sites include the Santa Barbara Channel, just off the coast of Santa Barbara, and Zaca Lake in northern Santa Barbara County (Fig. 1). Oak woodland, chaparral, coastal-sage scrub, and grassland comprise the majority of the vegetation in the region. This area was one of the earliest settled by Spanish missionaries and provides an opportunity to identify the effects of European impacts on vegetation. Repeat photography is used to help illustrate changes in the last century.

### STUDY AREA

*Santa Barbara Basin.* The Santa Barbara Basin (34°11'–34°16'N; 120°01'–120°05'W), is located between mainland California and the Channel Islands (Fig. 1). The center of the basin has a maximum depth of ca. 590 m and the bottom waters are normally anoxic. Because of the absence of a bottom fauna seasonal differences in sediment density are preserved as varves, and these have been used to establish a high resolution chronology of the last 560 years (Soutar and Crill 1977; Schimelman et al. 1990).

The source region for pollen deposited in the Santa Barbara Basin is the coastal plain and Santa Ynez Mountains. *Quercus agrifolia* appear dominant on north-facing slopes, in canyons, and in mesic sites along the coastal marine terrace. West and

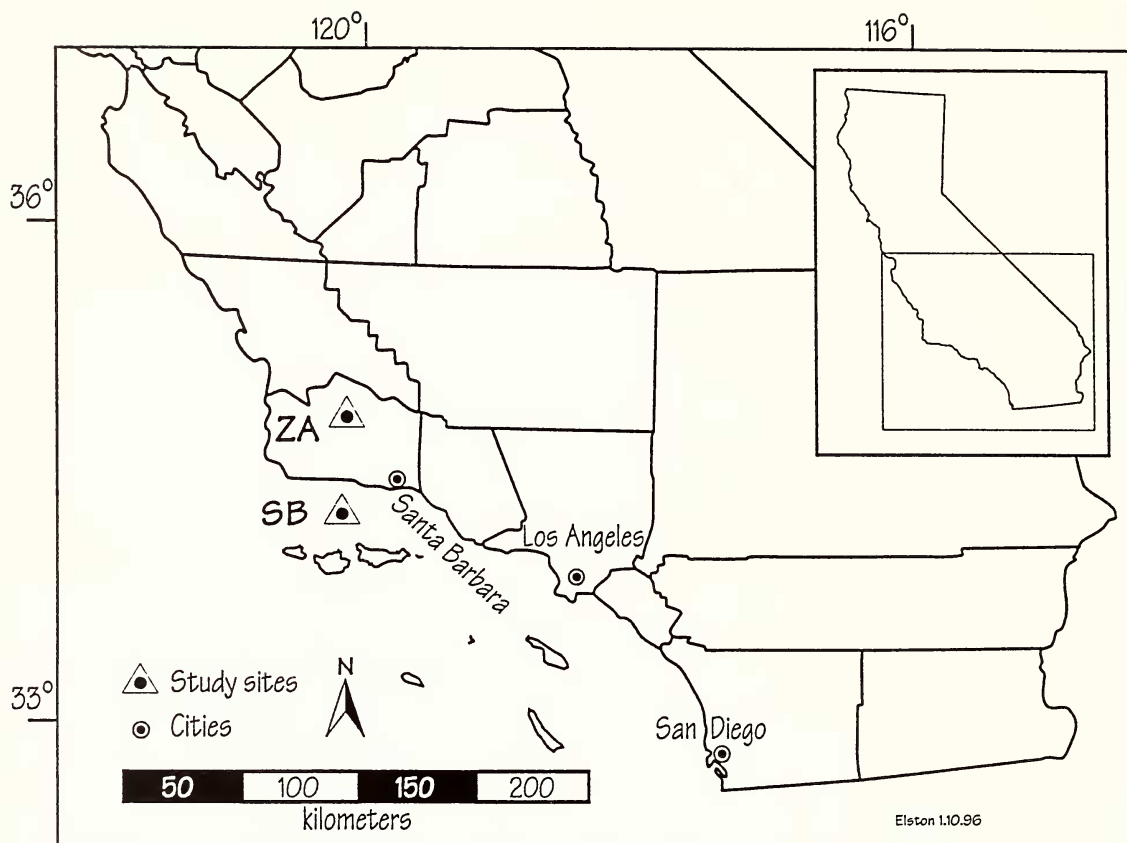


FIG. 1. Location map of the Santa Barbara Basin core site (SB), and Zaca Lake (ZA).

south facing slopes are dominated by chaparral, and coastal-sage scrub. Along the coastal plain introduced grasses and herbaceous plants are common (Ferren 1985). *Pinus muricata* grows in the Santa Ynez Mountains northwest of Santa Barbara although its distribution is restricted (Griffin and Critchfield 1976).

**Zaca Lake.** Zaca Lake ( $34^{\circ}36'36''\text{N}$ ;  $120^{\circ}02'17''\text{W}$ , elev. 730 m) is in the San Rafael Mountains, within the Los Padres National Forest, approximately 50 km northwest of Santa Barbara. Two massive Quaternary landslides blocked Zaca Creek to form the lake (Hall 1981). The lake is steep-sided and slopes to a flat bottom 13 meters in depth. Surface area is 6.9 ha. and the maximum length is 350 m.

The lake lies at the transition zone between oak woodland at lower elevations and pine forest at higher elevations. *Quercus agrifolia*, *P. coulteri*, *P. ponderosa*, and *P. sabiniana* are co-dominants around the lake. South-facing slopes are characterized by *Ceanothus* spp., *Arctostaphylo* spp., *Yucca* spp., *Salvia* spp., and *Artemisia californica*. Canyons include small stands of *Q. douglasii*, *Q. chrysolepis*, and *Calocedrus decurrens*. Small patches of exotic pines remain as a legacy of tree planting

at the turn of the century (Blakely personal communication). Ornamental conifers planted near the lake include *Sequoia sempervirens* and *Cedrus deodara* (Peterson 1980).

#### METHODS

Santa Barbara Basin cores SABA 87-1 and 88-1 were recovered by researchers from Scripps Institute of Oceanography with a Soutar Box Corer and a Kasten Corer (Schimmelman et al. 1990). All cores were initially sampled at near annual resolution, but the pollen analysis was based on sub-samples which represented consecutive, ca. 5 year intervals. An equal weight of sediment was taken from each annual sub-sample. Fifty-nine samples were analyzed from the period 1425 to 1985.

Two sediment cores were recovered from Zaca Lake in May, 1992 using a modified square-rod Livingstone piston corer fitted with a 5 cm diameter plastic tube liner; a 910 cm core (core C) and an overlapping 865 cm core (core D). While still in the plastic tube, cores were X-radiographed at the University of California Museum of Paleontology to record stratigraphy and density changes. Magnetic susceptibility and Gamma-ray analyses were carried out at the United States Geologic Survey

laboratories in Menlo Park. Sediment samples (0.5 cc) were then removed for pollen analysis.

Standard techniques were used to concentrate pollen (Faegri and Iversen 1975). A known quantity of *Lycopodium* spores was introduced as a control to calculate absolute pollen concentration and accumulation rate (Stockmarr 1971). A minimum of 400 pollen grains were counted for each level. For Zaca Lake, aquatic and riparian pollen types were counted but excluded from the pollen sum.

## RESULTS

### Santa Barbara Basin

**Chronology.** The Santa Barbara Basin varve chronology has been corroborated by radiometric dating, cross-correlation with tree-rings and correlation with hydrological data (Soutar and Crill 1977; Koide et al. 1972; Krishnaswami et al. 1973; Hulsemann and Emery 1961). The chronology used here is that of Schimmelman et al. (1990), and Schimmelman et al. (1992). Varve counts were made using high quality X-radiographs and age assignments were checked against distinctive marker layers of known events such as El Niño periods, floods, and oil spills. The estimated precision of the time scale is  $\pm 1$  year for 1900 to 1987,  $\pm 2$  years from 1900 to 1840,  $\pm 5$  years from 1840 to 1750, and  $\pm 10$  years at the 1425 level.

**Taxonomy.** Taxonomic nomenclature follows Hickman (1993). Forty-eight pollen and spore types were identified (Mensing 1993). Percentage abundance of the nine most important types is shown in Figure 2. *Quercus* probably represents *Q. agrifolia*, by far the dominant tree species in the region. Additional, but less important sources may include *Q. lobata*, which is important in the Santa Ynez drainage, *Q. durata* and *Q. dumosa* which are found in association with chaparral, and *Q. tomentella* from the Channel Islands. *Pinus* would primarily be *P. muricata*, *P. sabiniana*, *P. coulteri*, and *P. ponderosa*. Following Heusser (1978), the taxonomically difficult group including Rhamnaceae and Rosaceae are combined. These taxa include many chaparral species and probably represent the genera *Ceanothus*, *Rhamnus*, *Adenostoma*, *Cercocarpus*, *Prunus*, and *Heteromeles*. *Artemisia* is primarily *Artemisia californica*. Other Asteraceae are difficult to identify below family level and have been combined in Figure 2. Poaceae and Polemoniaceae also are not identified below the family level. Several native taxa from the Brassicaceae are present in small quantities early in the record; however, alien taxa became important in California in the early 19th century and the pollen increase probably represents introduced species. *Erodium* has been identified to the species *Erodium cicutarium*, a Mediterranean annual (Mensing and Byrne in press).

**Pollen analysis.** Below 1760, *Quercus* shows few changes; however, after 1760 the record be-

comes increasingly variable. Beginning in 1870, *Quercus* steadily increases from 20% to 42%, twice as high as the average during the pre-European period. *Pinus* remains below 10% through most of the record, and shows virtually no change. Although Rhamnaceae and Rosaceae show high variability, no long term trends appear over the 460 year period. *Artemisia* averages 7% and shows little variability for the first 400 years of the record, then, from 1820 to 1985 it increases to an average of 10%.

Asteraceae averages 20% from 1435 to 1700, but then begins to decline, dropping to only 7% percent in 1970. Poaceae declines at a slow but fairly constant rate through most of the record, but clearly increases between 1945 and the present. The Polemoniaceae are primarily insect pollinated, consequently only small quantities of pollen reach the Santa Barbara Basin. Polemoniaceae is present in virtually every level between 1425 and 1795, averaging nearly 1% of the pollen sum. In the last two centuries, Polemoniaceae is commonly absent, Brassicaceae is infrequent prior to 1825, but increases substantially in the modern period, most likely due to the introduction of European Brassicaceae. *Erodium* first appears in the pollen record in 1755 and is continuously present after that date.

### Zaca Lake

**Chronology.** The Zaca Lake chronology was developed using core D (0–0.5 m depth) and core C (0.5–2.75 m depth). Both cores clearly record a complex stratigraphy of laminations, dark silty layers, and dense clay layers described in earlier studies (Caponigro 1976; Peterson 1980). X-radiographs were used to correlate core stratigraphy with that described by Caponigro and Peterson. The chronology was developed using core-to-core correlation, radiocarbon dating, and the first appearance of two exotic pollen types (*Erodium* and *Cedrus*).

The base of the core section analyzed gave a radiocarbon age of  $2510 \pm 70$  BP (Beta-55301) (Calendar calibration B.C.  $661 \pm 150$ , Stuiver and Reimer 1986) (Fig. 3). The first occurrence of *Erodium* at 110 cm depth is assigned a date of  $1830 \pm 40$ . The data and error estimate are approximated from the Santa Barbara Basin data (Mensing and Byrne in press), and the species dispersal ability. The date of 1953 at the 47 cm depth is based on a  $^{137}\text{Cs}$  peak identified by Caponigro (1976). The first appearance of *Cedrus* pollen at 35 cm dates to 1964 assuming a 15 year maturation period following the first planting in 1949 (Peterson 1980). The disparity in sedimentation rate between the upper core (110 cm in 160 years) and the lower core (165 cm in 1500 years) suggests that the radiocarbon age may be artificially old. Even assuming no changes in sedimentation rate, the lower half of the core would span at least two centuries of vegetation history prior to Spanish settlement.



Santa Barbara Basin

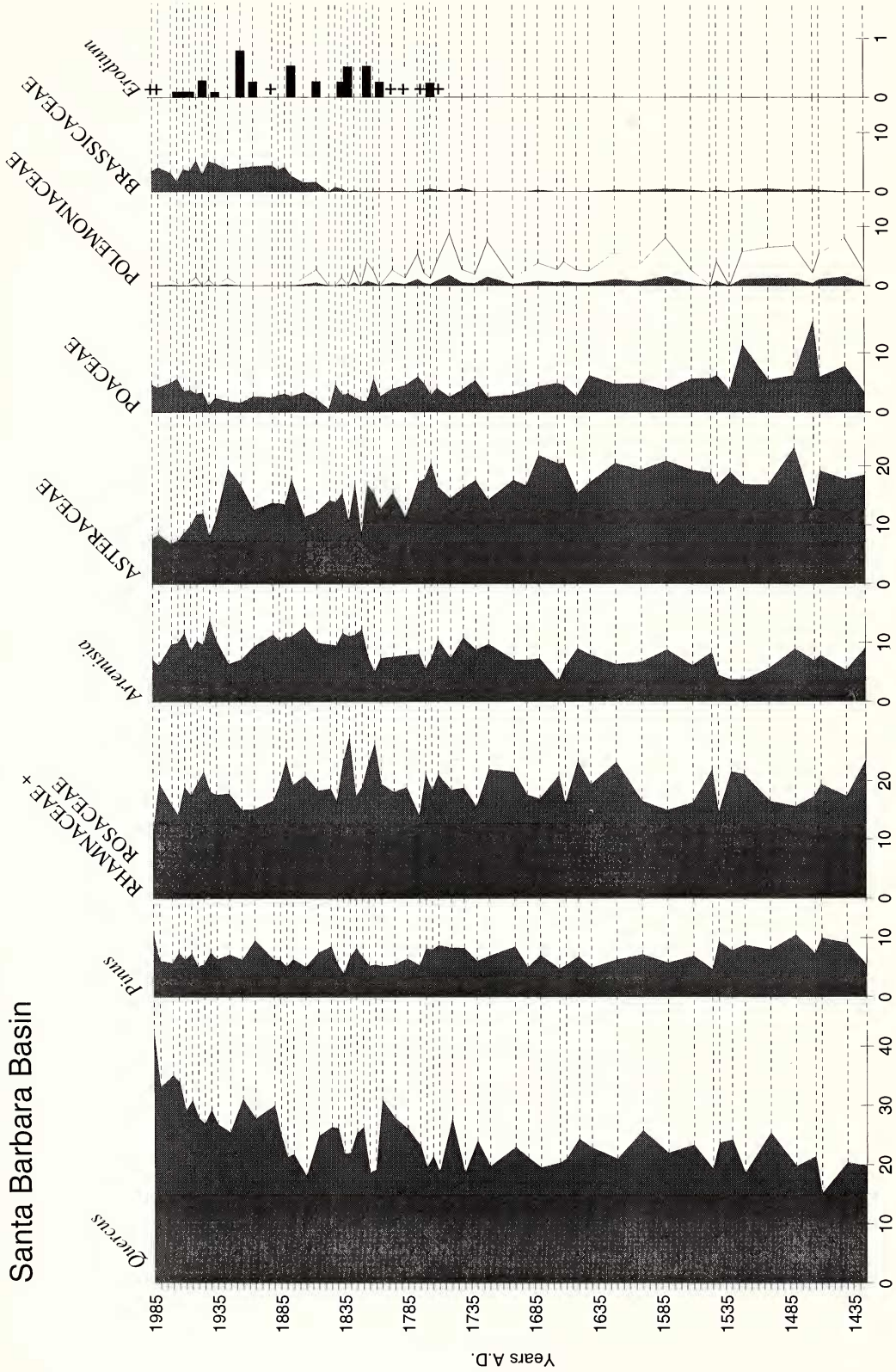


Fig. 2. Selected pollen types from the Santa Barbara Basin. Sums are expressed as a percentage of total pollen and spores excluding poorly preserved unidentified grains. The unshaded area under Polemoniaceae represents five times exaggeration. Note the scale change for Erodium (+) represents a level where Erodium pollen was identified by scanning (Mensing 1993).



Zaca Lake

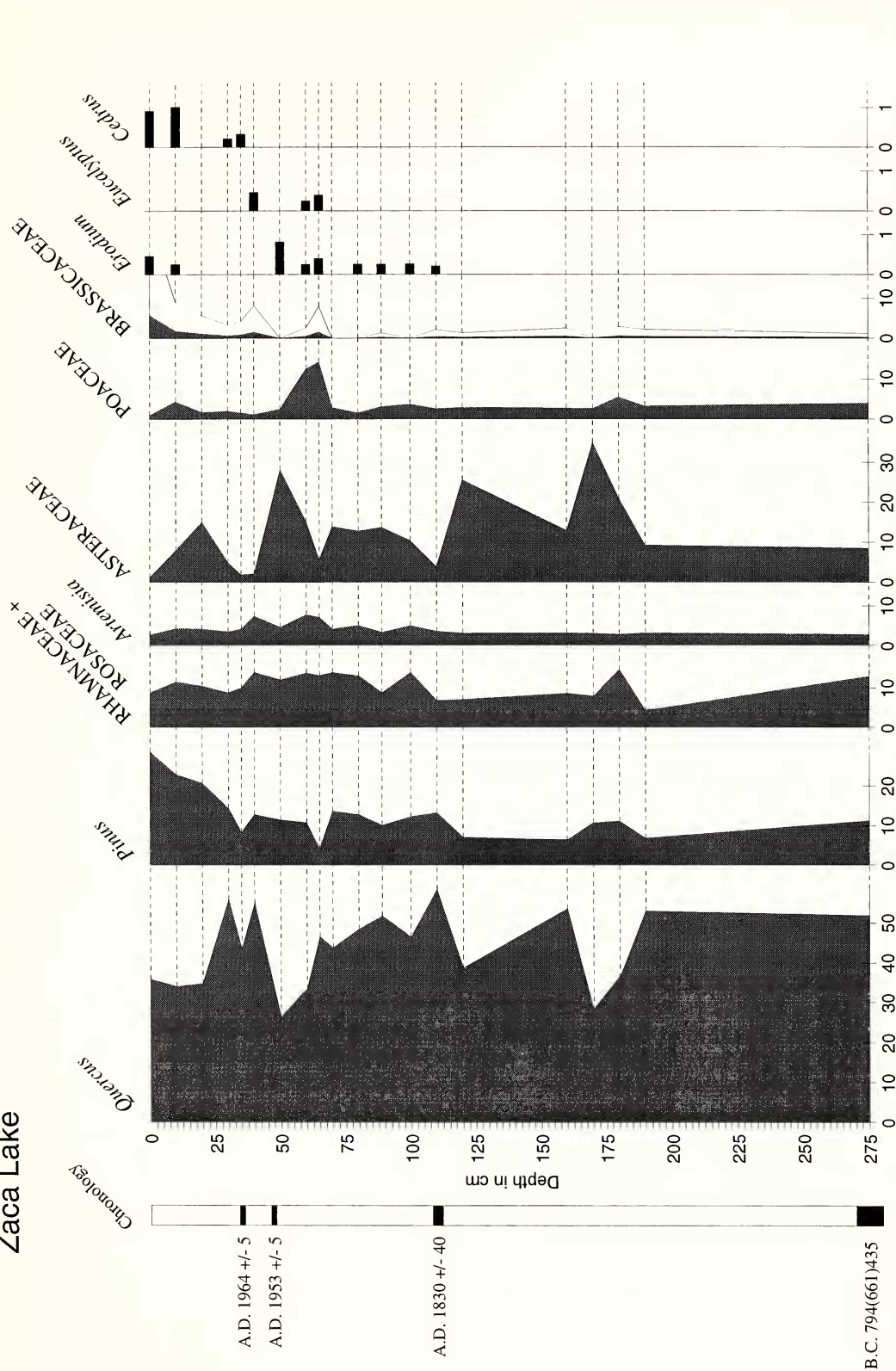


FIG. 3. Selected pollen types from Zaca Lake. Sums are expressed as a percentage of total pollen and spores excluding aquatics (*Typha*, *Cyperaceae*, and *Ruppia*), riparian taxa (*Salix* and *Platanus*) and poorly preserved unidentified grains. The unshaded area under Brassicaceae represents five times exaggeration. Note the scale change for *Erodium*, *Eucalyptus*, and *Cedrus*.

**Taxonomy.** Fifty-four pollen and spore types were identified (Mensing 1993), of which ten taxa are graphed in Figure 3. Species of oaks in the region that most likely contribute pollen to the site include *Q. agrifolia*, *Q. lobata*, *Q. durata*, *Q. chrysolepis*, *Q. wislezenni*, and *Q. douglasii*. Of these species *Q. agrifolia* and *Q. lobata* dominate the region today. *Pinus* includes *P. ponderosa*, *P. sabiniana*, and *P. coulteri* as well as *P. attenuata*, planted around the turn of the century. Rhamnaceae/Rosaceae includes taxa similar to those described for the Santa Barbara Basin as well as *Cercocarpus betuloides*, *Prunus ilicifolia*, *Heteromeles arbutifolia*. Asteraceae around Zaca Lake primarily represent herbaceous taxa. Brassicaceae probably include introduced mustards in the post-European period. *Erodium* was identified as *Erodium cicutarium*. *Eucalyptus* is no longer present at the site and the type is unknown. *Cedrus* is from *Cedrus deodora* planted near the lake.

**Pollen analysis.** Twenty-six levels were analyzed at approximately 10 cm intervals. Six levels were excluded from the analysis because of extremely high percentages of Asteraceae pollen presumably associated with erosion events. Dense clay layers are present in the core at 130–150 cm and 200–240 cm depth. These lenses are associated with above average magnetic susceptibility and generally low organic content (Mensing 1993). High magnetic susceptibility readings generally result from deposition of iron bearing sediments. Peterson (1980) hypothesized that these layers may be associated with periods of higher than average erosion. Asteraceae pollen is particularly resistant to biodegradation and during periods of high runoff, pollen accumulated on the soil surface may have been washed into the lake biasing the sample.

For most of the record, *Quercus* pollen remains between 40–50%. Low percentages are seen at the 50–60 cm, 120 cm and 170–180 cm depths. The declines are mirrored by increases in Asteraceae. These strata are not clay layers; however, they show above average magnetic susceptibility suggesting that they may also be associated with erosion events. Organic rich lake sediments (gytja) commonly had 50% *Quercus* pollen. In the upper part of the record, from about 1970 to the present, *Quercus* averages 35%. Unlike previous decreases in *Quercus*, Asteraceae also declines during this time.

*Pinus* values remain stable at about 10% through most of the core then begin to increase rapidly to 29% in the mid 1900's. The Rhamnaceae/Rosaceae curve shows little variation averaging about 12%. Similarly, *Artemisia* varies little, reaching as high as 7% between 40–65 cm, but remaining at less than 4% for most of the record.

Asteraceae is the most important herbaceous pollen type. The record is highly variable, ranging from 1% to 34%. Poaceae, which remains fairly constant at about 2–3% for most of the core shows

an interesting short term increase at the 60 and 65 cm levels (ca. 1920 to 1930), jumping up to 14%. *Zea mays* (corn) pollen was also found in the 65 cm level, suggesting a period of local cultivation. Brassicaceae is present at about 1% in the core section below 65 cm (ca. 1920). From 65 cm up to the surface level, Brassicaceae steadily increases from 1% up to 6%. *Erodium* first appears in the core at 110 cm depth and is present in ten levels. *Eucalyptus* is present in three levels with approximate dates of 1920, 1930, and 1960. *Cedrus* first appears in 1964 and increases in abundance in the surface samples.

## DISCUSSION

**Oak woodlands.** The Santa Barbara pollen record shows no significant vegetation changes during the pre-European period. The evidence suggests that oak woodland populations remained stable for up to four centuries. Beginning around 1870 and continuing until 1985, percent *Quercus* pollen steadily increases to its highest level in 560 years. Principal components analysis of pollen accumulation rates indicates that the abundance of *Quercus* pollen has indeed increased over the last century (Mensing 1993). The twofold increase of *Quercus* pollen during the last century strongly suggests an increase in oak woodlands in the Santa Barbara region. This increase may be from an increase in woodland density, expansion of oak woodland habitat, or a combination of the two.

The Zaca Lake record is less clear concerning oak woodlands. For most of the record, *Quercus* is the dominant pollen type with maxima averaging 50 percent. Periodic declines in *Quercus* consistently correspond with increases in Asteraceae. An increase in individuals of the Asteraceae, locally composed primarily of herbaceous annuals, would not displace oak woodlands. Since decreases in *Quercus* are not associated with increases in woody taxa, I suggest that oak populations in this area remained stable prior to the mid-1900's. Since 1950 another woody taxon, *Pinus*, has increased substantially. The increase in the importance of *Pinus* recorded in the pollen record is confirmed by repeat photography (Fig. 4). Scattered pine groves, visible on the distant slopes in the 1895 photograph, now appear as dense forest. Today, the understory surrounding the lake is thick with young pines and oaks, but pines over-top oaks in most places. Zaca Lake is located at the transition between oak woodland and coniferous forest. Although oaks may be increasing to some extent at this site, the primary signal in the pollen record, supported by evidence from repeat photography, is an increase in the importance of pines.

This study presents the first high-resolution paleoecologic records to document changes in California oak woodlands from the pre-European period to the modern period. Of significance here is that





FIG. 4. Repeat photography of Zaca Lake taken from the north shore looking east. The upper photograph was taken by a local Santa Barbara photographer ca., 1895 (courtesy Santa Barbara Historical Society Museum). The lower photograph is by the author, 1992.

*Q. agrifolia* populations in the Santa Barbara area have increased in the recent century, after a long period with no apparent changes. Other studies, primarily stand age analyses of *Q. douglasii*, have also documented increases in woodland density (White 1966; Vankat and Major 1978; Mensing 1992); however, these studies do not extend to the pre-

European period. A resampling of permanent plots in northern California found that *Q. douglasii* have increased over the last 60 years, with live oaks beginning to emerge as co-dominants (Holzman 1993).

In general, there is concern that California oak woodlands are in decline. A recent assessment of



*Q. douglasii* found that 87% of the study locations were experiencing a net loss in both tree density and canopy cover (Sweicki et al. 1993). Studies have documented negative impacts of human-caused environmental change to oak woodlands throughout the state including direct loss of woodlands through clearing (Bolsinger 1988; Rossi 1980) and poor regeneration as a result of livestock grazing, invasion of annual grasses, and other changes (Griffin 1971; Bartolome et al. 1987; Borchert et al. 1989; Harvey 1989; Gordon and Rice 1993; Muick 1995).

To understand the full extent of these changes on California oak woodlands, it is valuable to have data on how current populations compare with those from the pre-European period. In this regard, paleoecologic studies provide important information to understand the long term implications of human-caused environmental change. This study suggests that *Q. agrifolia* populations in the Santa Barbara region have increased during the modern period, a time of significant human-caused environmental change.

The increase in *Q. agrifolia* is most apparent in the 1900's. I believe that the environmental change most likely to have resulted in an increase of oak woodland is a change in fire regime. In the absence of fire, *Q. agrifolia* tends to increase. Density and canopy cover for *Q. agrifolia* at Burton Mesa in Santa Barbara County was found to be highest on sites without recent fires (Davis et al. 1988). McBride (1974) examined plant succession in the Berkeley hills and suggested that in the absence of recurrent fires, *Q. agrifolia* and *Umbellularia californica* would succeed *Baccharis pilularis*. In a comparison of vegetation dynamics on burned and unburned plots at Gaviota State Park west of Santa Barbara, Callaway and Davis (1993) found that chaparral was being converted to oak woodland at a rate of 0.12% per year in the absence of fire. They predicted that with the absence of fire and grazing, oak woodland would dominate a larger proportion of the landscape.

The Chumash regularly set fires along the coastal plain, and this practice continued even after establishment of the missions (Timbrook et al. 1982). Many of these grass fires probably burned through the understory of adjacent oak woodlands, killing oak seedlings and saplings. Trees of less than 7.5 cm diameter breast height have bark approximately 0.6 cm thick and may be killed by low intensity fires (Plumb and Gomez 1983). This process would have maintained open oak woodlands similar to the oak parks typically described by early Spanish explorers. Since the turn of the century, urban and agricultural development has concentrated in areas dominated by grassland and oak woodland. Although urban and agricultural development have been responsible for clearing oaks, fire protection in developed areas favors oaks in nearby wildland settings (Davis et al. 1988; Callaway and Davis

1993). The Santa Barbara Basin pollen record suggests that the last 100 years have produced such an increase in oaks in the Santa Barbara region.

Reduction in fire frequency may also be responsible for the recent increase in woodland and shrub cover at Zaca Lake. Fires have been systematically recorded in the Los Padres National Forest since 1911. Three fires have burned on the chaparral slopes to the northwest of the lake; however, no fires larger than a few acres have burned the wooded slopes in the upper Zaca Lake watershed (Los Padres National Forest Fire Statistical Database). Here, absence of fire appears to have favored pines over oaks. Zaca Lake is located at the pine/oak ecotone. The tendency for pine to invade oak woodland following fire suppression has been clearly demonstrated in Yosemite Valley where open oak meadows were converted to closed coniferous forest after fire suppression (Reynolds 1959; Gibbens and Heady 1964; Anderson and Carpenter 1991). The Zaca Lake pollen record suggests that at upper elevation sites where coast live oak grows with pines, coniferous forest will replace oak woodland in the absence of frequent fire.

*Chaparral, coastal-sage scrub, and herbaceous vegetation.* There is some debate concerning the impact of European settlement on chaparral, coastal-sage scrub, and herbaceous vegetation. Dodge (1975) argued that grassland was much more extensive during the pre-European period because frequent low-intensity fires cleared out young shrub seedlings. He concluded that heavy grazing and fire suppression have reduced low-intensity fires and permitted shrub invasion of vast areas formerly dominated by grasses. Timbrook et al. (1982) echoed this sentiment and concluded that chaparral has increased in density and extent over the last 200 years because of suppression of grassland burning. Furthermore, they suggested that a grassland which dominated the Santa Barbara coastal plain and foothills has been largely replaced by coastal-sage scrub as a result of fire suppression.

The pollen record does not support the idea that chaparral has expanded over the last 200 years. The Rhamnaceae/Rosaceae curve from each site show virtually no consistent trends (Figs. 2, 3). If anything, the Santa Barbara Basin diagram shows a modest decline in chaparral taxa in the recent century. The pollen record suggests that chaparral has not expanded its range in response to European impacts.

There is some evidence to suggest a modest increase in the importance of coastal-sage scrub over the last 200 years. *Artemisia* averages 7% of the pollen sum from the period between 1425 and 1820 (Fig. 2). However, beginning in 1820, it increases to 12%, and averages 10% between 1820 and 1985. Pollen percentage remains at the higher levels except for two brief declines centered on 1920 and 1980. At Zaca Lake *Artemisia* averages 2.7% prior

to about 1800, then increases to an average of 5.0% in the upper core (Fig. 3). Although this may represent a true increase, it is difficult to interpret too much from such a small change.

Comparison of burned and unburned plots in Santa Barbara County found that coastal-sage scrub invaded grassland in the absence of fire, but frequent fire favored grassland (Callaway and Davis 1993). Westman (1976) also found that coastal-sage scrub replaced undisturbed grassland when fire was removed. In northern California, *Baccharis pilularis* was found to invade grassland during periods of low fire frequency (McBride and Heady 1968). Reduced fire frequency along the coastal plain may have favored a slight expansion of coastal-sage scrub; however, there is no evidence that this impact affected the distribution or abundance of chaparral.

Pollen evidence of herbaceous taxa shows that the invasion of alien species into grasslands began very early. *Erodium* first appears in the pollen record in 1760, nearly a decade prior to the first Spanish settlement in San Diego and more than 20 years before the founding of the Mission Santa Barbara (Fig. 2). The pollen has been identified as *Erodium cicutarium* (Mensing and Byrne in press), a Mediterranean native, and provides evidence that the invasion and transformation of herbaceous vegetation began prior to European settlement. Polemoniaceae averages nearly 1% and is consistently present through the 1700's. Asteraceae, the dominant herbaceous pollen type, averages 18% in the pre-European period. Both taxa decline markedly in the modern period. The decline becomes particularly pronounced after the arrival of alien Brassicaceae which became widespread along the coastal plain in the early 1800's (Cleland 1951).

#### CONCLUSIONS

The evidence from this study suggests that oak woodlands in the Santa Barbara region have increased during the last 100 years. The nature of this increase varies between sites. In the Santa Barbara area, *Q. agrifolia* appears to have increased beginning in the late nineteenth century. Fire suppression on the coastal plain has probably been the main factor contributing to this increase. The Chumash are reported to have periodically set fires; however, with an increase in settlement and development, burning has been suppressed. In the absence of fire, *Q. agrifolia* has increased in density. A policy of fire suppression appears to favor *Q. agrifolia*, and where fire return intervals are long, oaks would be expected to continue to increase in density.

At higher elevations where *Q. agrifolia* grow alongside pine, such as at Zaca Lake, fire suppression appears to have favored pine over oak. Here, coniferous forest is expanding into oak woodland. The taller pines may eventually shade out the slower growing oaks if the present trend continues.

The pollen record shows that prior to European settlement, oak populations had been stable for at least three centuries. In the past two centuries, oak populations have changed in response to European impacts, including the introduction of grazing, suppression of fire, and a shift in understory composition. In some cases, these changes appear to have favored oaks, creating woodlands more dense than during the pre-European period.

Chaparral does not appear to have expanded significantly in response to European land use changes. Coastal-sage scrub may have expanded some; however, the evidence for this change is weak. Invasion and transformation of grassland appears to have begun particularly early with the first alien taxa reaching the area even before the first Spanish settlement of California.

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